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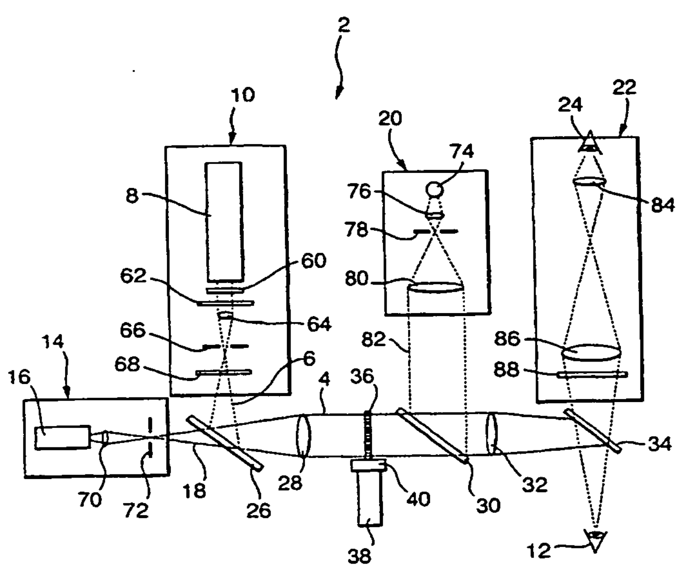

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(57) Abstract: The invention provides an optical system, including a powerful first light source forming a main light beam; an optical arrangement for focusing the main light beam onto a target plane, and a diffraction grating assembly having a plurality of diffraction gratings movably coupled in the assembly, for selectively introducing at least one grating in a plane transversing the main light beam; each of the gratings having a predetermined pattern of grating functions for spatial modulation of the main light beam so as to divide the beam into a multiplicity of sub-beams to be focused on the target plane. The invention further provides a method for treating a target plane with a light beam and a method for treating a tissue at a surgical site.

TREATING A TARGET WITH A DIVIDED LASER BEAM

Field of the Invention

The present invention relates to optical systems and methods, particularly to laser systems and methods for surgical and other applications. More specifically, the present invention concerns laser systems and methods for diabetic retinotherapy treatment.

Background of the Invention

While the present invention is useful in many fields and can be realized in treating surfaces or tissues of many kinds, the specification will be mainly directed to a major application of the invention in the field of medicine.Diabetes in the United States affects approximately 2-4% of the population. This disease may progress to cause diabetic retinopathy, that typically occurs in two forms. In a first, non-proliferative form, retinal capillaries become ischemic, such that not enough blood reaches the retina through these capillaries. A second form is proliferative, in which new vessels form on the surface of the retina and extend into the vitreous, leading to retinal detachment or large scale hemorrhage in the vitreous. The progression of these conditions results in serious losses of vision, and commonly in blindness.

The most common of conventional therapies for diabetic retinopathy involves photocoagulation. Accordingly, a light beam is focused on the retina to produce a burn or coagulation spot. The light beam is emitted from conventional lasers by conventional laser operating procedures. These procedures typically employ, e.g.,a single Argon blue-green or green laser, or a Krypton red laser. One Argon blue-green laser is commercially available as a Cavitron™Model 3000 Argon Photocoagulation Laser.

One early procedure, wherein an Argon laser focuses intense light on individual spots on the retina, is known as Pan Retinal Photocoagulation (PRP).

Upon reaching the retina, the light is converted to heat, coagulating cells and surrounding tissues of the retinal pigment epithelial cells. Generally, this procedure

improves retinal circulation, resulting in a better regulatory response to hypoxia and decreased blood flow.

Contemporary therapies have evolved from this early therapy. One contemporary therapy is commonly referred to as Point-by-Point. In this therapy, a surgeon makes approximately 1600 to 2000 burns of approximately 500 micrometers in diameter, delivered from a conventional Argon blue-green laser or a Krypton red laser, at powers of about 200 to 600 mW and for a duration of 0.1-0.8 sec. The laser energy reaches the eye through a special contact lens, a Goldman lens or any other type, so as to be delivered at an intensity sufficient to whiten the overlying retina. In performing this procedure, the recommended space between burns was to one-half to one burn diameter (250 to 500 μm).

These treatments have been helpful in reducing severe vision loss. They have also been cost-effective, saving costs associated with disability, blindness, and the like. However, these methods, including the conventional therapies, continue to have drawbacks.

Typically, conventional treatments involving the above-mentioned lasers require approximately two to three treatments of twenty to thirty minutes each, in order to place the large numbers of burns. This is made more difficult by the fact that these treatments may be painful, and many older patients simply can not handle repeated treatments of this length and the pain involved. Additionally, such procedures typically destroy approximately 14% of the total retinal area and result in partial retinal damage at the periphery of each burn.

Finally, in the known procedures, the need to correctly aim the laser beam for each laser burn in order to produce the resultant grid require extremely high accuracy, thus varying from surgeon to surgeon.. Furthermore, should the gaps of about 250 to 500 microns and a duration of 0.1 sec between burns be too narrow or too wide, additional or repeated treatments may be required and the damage suffered as a result of poor spacing may be irreversible. Redoing previously burned areas is especially painful, because of the scar tissue that formed as a result of the previous

burns.

U.S. Patent 5,921,981 describes a surgical multi-spot laser device providing multi-spot laser beams from a single laser source. The device provides means for splitting the single laser beam, which means includes an optic fiber cable or microlens array disposed between the laser source and the optical spots. Such means cannot be changed during operation of the device, and are very limited in selectively providing suitable spatial distribution between split beams.

Summary of the Invention

It is therefore a broad object of the present invention to ameliorate the drawbacks of the known devices and to provide a optical system which is adaptable for treatment of surfaces and tissue according to specific needs.

The invention achieves the above objective by providing an optical system, comprising a powerful first light source forming a main light beam; an optical arrangment for focusing said main light beam onto a target plane, and a diffraction grating assembly having a plurality of diffraction gratings movably coupled in said assembly, for selectively introducing at least one grating in a plane transversing said main light beam; each of said gratings having a predetermined pattern of refractive indices for spatial modulation of said main light beam so as to divide the beam into a multiplicity of sub-beams to be focused on said target plane.

The invention further provides a method for treating a target plane with a light beam, comprising providing a powerful first light source forming a main light beam and an optical arrangement for focusing said light beam onto a target plane; providing a diffraction grating assembly having a plurality of diffraction gratings, each of said gratings having predetermined grating functions for effecting spatial modulation; selecting at least one of said diffraction gratings, and positioning said selected diffraction grating in a plane traversing said light beam, so as to cause said beam to split into a plurality of sub-beams to be focused on said target plane.

Brief Description of the Drawings

The invention will now be described in connection with certain preferred embodiments with reference to the following illustrative figures so that it may be more fully understood.

With specific reference now to the figures in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

In the drawings:

Fig. 1 is a schematic diagram of the surgical laser system of the present invention;

Figs. 2-4 illustrate Bragg diffraction gratings for use with the system of thepresent invention;

Figs. *5a* and *5b* are schematic diagrams illustrating the recording and readout geometries of a thick phase transmission hologram;

Fig. 6 illustrates a surface relief diffraction grating for use with the system of the present invention;

Figs. *7a* and *7b* are array assemblies for use with the diffraction gratings of the present invention;

Fig. 8 depicts another embodiment of a diffraction grating unit in accordance with the present invention, and

Fig. 9 is a schematic diagram of a further embodiment of a surgical laser system according to the present invention.

Detailed Description of Preferred Embodiments

Referring now to Fig. 1, showing a surgical laser system 2 of the present invention in use in an ophthalmic procedure. Specifically, the shown system 2is suitable for the treatment of diabetic retinopathy. It should be noted, however, that other ophthalmic, as well as other surgical procedures, are also possible and medically permissible with the system of the present invention, or modifications thereof.

The system 2 includes a main channel 4 which receives and focuses an operating powerful main beam 6 emitted by a main laser 8 of the main channel laser unit 10, for producing the requisite burn or coagulation spots on a target plane, e.g., an eye 12, particularly on the retina of the eye. An auxiliary, or second light-source unit 14 preferably includes a laser 16 or other light source, aligned with the main channel 4, including the path of operating beam 6, and in coordinated alignment with the main laser 10, such that the laser 16 preferably provides an aiming beam 18 for the operating beam 6 on the eye 12 of the patient. Channel 4 also receives light from an illumination channel 20, for illuminating the surgical site proximate the eye 12 of the patient, and is in alignment with a viewing channel 22 simulating an eye 24, through which the surgeon can view the eye 12 of a patient during the procedure.

The main channel 4 also includes a first beam combiner 26, that can be embodied by a partially reflective mirror, but could also be a cubic beam splitter, or any similar optical element. The first beam combiner 26 merges the operating beam 6 and the aiming beam 18, such that they travel along a single, coincident pathway in the main channel 4 to the eye 12 of the patient. A first lens 28, preferably a collimating lens, is located downstream from the first beam combiner 26. Continuing downstream, there are located a second beam combiner 30 for receiving the beam from the illumination channel 20, as well as the beams from the main laser 8 and auxiliary laser 16; a second lens 32, preferably a focusing lens: and a third beam combiner 34, for combining the beams of the viewing channel 22 with the illumination channel 20 and beams 6 from the main laser 8 and auxiliary laser 16.

A diffraction grating assembly 36 includes a diffraction grating unit 38 affixed on a support 40. The diffraction grating unit 38 can be formed of single or multiple diffraction gratings 42*a* to 42*d* (shown in Figs. 2-4 and 6) and/or grating arrangements 44*a*, 44*b*, 46 (shown in Figs 7*a*, 7*b* and 8). The diffraction grating assembly is preferably located intermediate the first lens 28 and the second beam combiner 30. The diffraction grating assembly 36 includes at least one diffraction grating for dividing the single mother or operating beam 6 and the aiming beam 18 into plural daughter or sub-beams. that are preferably equally spaced beams of equal intensity, but can be arranged in any predefined, desired pattern or array. The diffraction assembly 36 could also be positioned elsewhere in the main channel 4, provided that the desired separated illumination is achieved on the image or target plane.

As mentioned above, the diffraction grating unit 38 can include a series of different gratings 42*a* - 42*d* configured in various patterns, dividing the main beam into various numbers of sub-beams. For example, the diffraction grating unit 38 can include grating arrangements 44*a*, 44*b* for forming a rotating array assembly 48 (Fig. 7a) and a translating array assembly 50 (Fig. 7b). These array assemblies include openings 52 for accommodating various gratings G_1-G_6, typically such as those detailed herein. Each different grating in the array assembly creates a different pattern at the surgical site, and the operator can decide at any time which pattern to use according to the medical situation, the energy needed for the treatment, the individual tolerance of the patient, and other considerations.

The gratings selected to illustrate gratings G_1- G_6 may even include transparent openings or holes, known as "null" gratings. These null gratings do not change the shape of the beam, and are particularly useful when only a single beam is desired.

The gratings G_1- G_6 may be selected by the operator as desired and moved into place by rotation about an axis 52 or translation in the direction of the arrow 54. The arrangements shown in the array assemblies 48 and 50 are only examples; other examples and other arrangements, in accordance with the procedure and/or treatment desired, are also permissible. Thearray assemblies 48, 50 may be used in multiples of

each other, as well as together in multiples. For example, a grating in one assembly that split the laser beam into three vertical beams may be combined with another grating in a second assembly that split the laser beam into three horizontal beams. to create a pattern of nine sub-beams arranged in a 3x3 array.

The main laser 8 could include an Argon laser, operable preferably within the visible light spectrum of 458-530 nm. Other lasers. such as Neodynium:YAG (Nd:YAG), having a wavelength of 1.06 μm and doubled frequency wavelength of 530 nm. and Krypton (670 nm) are also suitable. These lasers can be continuous or pulsed. Other wavelengths are also suitable for the aforementioned lasers, depending on the specific application. Alternatively, any other laser source having the desired power and wavelength can be used.

The exiting operating beam 6, upon moving downstream to the main channel 4, is then subjected to a filter 60, such as an interference filter or the like. One exemplary filter can be a filter that cuts out illumination having a wavelength of 1.064 micrometers, for a doubled frequency Nd:YAG laser. Moving further downstream, there is disposed an intensity-reducing device 62, such as a variable attenuator, a lens 64, such as a focusing lens, a spatial filter 66, and a time controller shutter 68, for exposing the operating laser beam 6 to the eye 12 of the patient.

The auxiliary laser 16 of the auxiliary unit 14 advantageously includes a diode laser, and is operable such that it produces an aiming beam 18, that is preferably visible (of wavelengths within the visible light spectrum) with a wavelength similar to that of the main laser 8. Within the auxiliary laser unit 14, moving downstream, is a lens 70, preferably a focusing lens, and a spatial filter 72 in accordance with that detailed above. The laser 16 in auxiliary unit 14 can be replaced by a light source such as a monochromatic or quasi-monochromatic light source, emitted from devices such as a light emitting diode (LED), to provide the requisite aiming beam.

Alternatively, auxiliary laser 16 can be altogether omitted from the above-described apparatus, provided that the main or first laser 8 operates with visible light. This is ordinarily achieved by reducing the intensity of the beam with a filter or

the like, such that, at this reduced intensity, the main laser 8 emits a beam that serves as both the operating beam 6 and the aiming beam 18.

Moving downstream toward the main channel 4, the illumination channel 20 advantageously includes a light source 74 such as a white light source; a first lens 76, e.g., a focusing lens; a spatial filter 78; and a second lens 80, preferably a collimating lens . The illumination channel 20 is in alignment with the main channel 4, whereby the exiting light beam contacts the second beam combiner 30.

Viewing channel 22 preferably includes a first lens 84, e.g., an ocular lens; a second lens 86, e.g., an objective lens; and filter 88, located downstream of the second lens 86. Theviewing channel 22 is aligned with the third beam combiner 34 of the main channel 4. The lenses 84, 86 create a system for imaging the retina of the eye 12, with the filter 88 functioning to protect the viewer's eye(s) 24 from being damaged by the operating laser beams. However, any other imaging system configuration, such a single imaging lens, can be used to image the patient's eye 12 into the operator's eye 24.

It is important to note that the arrangement shown in Fig. 1 is only an example, and other arrangements are also possible, in accordance with the procedure and/or treatment desired. For example, most of the optical elements shown in the setup, including the diffraction grating, are transmissive elements. However, there are cases where reflective elements are more appropriate for the optical operation, such as when the main operating wavelength is in the far infra-red or ultraviolet spectral domains. The diffraction grating can also be materialized as a reflection grating.

Figs. 2-4 and 6 show diffraction gratings 42*a*-42*d* that may be used in the diffraction grating unit 38 in the system 2 of the present invention. Bragg gratings or phase volume gratings 42*a*-42*c* are one type of diffraction grating suitable for use with system 2, while surface relief gratings 42*d* are also suitable. These gratings 42*a*-42*d* function to split the single or main beam, both operating and aiming beams, into multiple sub-beams, preferably of equal intensity. These sub-beams are an array of plane waves that are focused by the lens 32. In the system 2 of the present invention,

when performing diabetic retinopathy there is produced an array of substantially equally intense (main to sub-beams) light spots on the retina.

In Figs. 2-4, the diffraction gratings 42*a*-42*c* are shown as two-dimensional plots. The various levels of shading in these figures denote a continuous modulation of the refractive index of the grating, with darker areas denoting a higher index and lighter areas denoting a lower index. These Bragg diffraction gratings are typically made of a material such as photopolymer or the like, that is preferably moderately flexible. The modulation of the refractive index of the grating material is performed by processes including interferometric recording. Fig. 2 illustrates a grating 42*a* with an index modulation formed of equally spaced-apart patterns 90. These patterns 90 serve to split the main beam(s) into two sub-beams.

Fig. 3 illustrates a grating 42*b* having index modulation, preferably at two-dimensional periodic intervals. The spatial modulation pattern of the index modulation is such that the grating 42*b* splits the main beam(s) into four sub-beams.

Fig. 4 depicts a grating 42*c* having index modulation, preferably at periodic intervals. The orientation of the index modulation is such that the grating 42*c* splits the main beam(s) into six sub-beams.

Gratings 42*a*-42*c* may be formed by recording a photosensitive emulsion material, such as a photopolymer, dichromatic gelatin or the like, to produce a thick phase hologram. The recording procedure of holograms is a conventional technique and can easily be utilized to fabricate the desired holograms.

Figs. 5*a* and 5*b* show further details of the thick phase holograms that form gratings 42*a*-42*c*. Fig. 5*a* illustrates the schematic recording, and Fig. 5*b* the readout geometries, of a phase volume transmission hologram 90, where $\overline{K}$ is the three-dimensional grating function of the hologram; *O*, *R*, *C* and *I* are the object, reference, readout and the image waves, respectively; *D* is the thickness of the emulsion; α_{o},, α_{R};, α_c and α_i are the off-axis angles of the object, reference, reconstruction and image waves and the off-axis angle of the grating function, respectively; and λ is the readout wavelength. Such an hologram can be used as a

building block for the desired multiple grating; here, with the condition $\alpha_c = 0$. That is, the readout wave in the shown setup is normal to the grating's plane.

When the readout geometry is identical to the recording geometry, the diffraction efficiency of a thick phase hologram is given by:

$$\eta = \sin^2(\varphi) , \qquad (1)$$

where the grating coupling coefficient is defined as:

$$\varphi = \frac{\pi\eta D}{\lambda\sqrt{\cos\alpha_i \cos\alpha_c}} , \qquad (2)$$

and η is the refraction-index modulation. To assure high diffraction efficiency, the relation:

$$\frac{2\eta D}{\lambda\sqrt{\cos\alpha_i}} = 2m-1 , \qquad (3)$$

must be fulfilled, where m is an integer (from now on, *m is chosen to equal 1)* and it is assumed that $\alpha_c = 0$. Hence, the necessary refraction-index modulation to achieve high diffraction efficiency is:

$$\eta = \frac{\lambda\sqrt{\cos\alpha_i}}{2D} , \qquad (4)$$

Eventually, an N number of different holograms can be recorded on the same emulsion, each one having a different output direction $(\alpha,\beta)_n$, n=1, N, where $\beta$is the off-axis angle in a plane normal to the plane of the page. An important parameter here is the number of channels that this multiple hologram can handle simultaneously. This number is actually the number of different holograms which can be multiplexed together on the same substrate without reaching the refraction-index saturation of the recording material. Namely, the total sum of the desired refractive-index modulation for all the multiplexed channels must be less then the allowed maximum index modulation η_{max} of

the recording material. It has been shown before that for recording materials such as dichromated gelatin or photopolymer, when the relation:

$$\sum_{n=1}^{N}\eta_n = \eta_{max}, \qquad (5)$$

is fulfilled, a large number of holograms can be multiplexed together on the same substrate with high efficiencies, negligible absorption and with no index saturation. Inserting Equation (5) into Equation. (4) yields the allowed maximum number of channels:

$$N \cong \frac{\eta_{max}}{\eta_n} \cong \frac{2\eta_{max} D}{\lambda\sqrt{\cos\overline{\alpha}_i}}, \quad (6)$$

where the average off-axis angle $\overline{\alpha_i}$ is defined as:

$$\frac{1}{\sqrt{\cos\overline{\alpha}_i}} \equiv \frac{1}{N}\sum_{n=1}^{N}\left(\frac{1}{\sqrt{\cos\alpha_i}}\right)_n . \qquad (7)$$

In addition, it is possible to use amplitude holograms instead of phase holograms. Namely, the grating function is set by amplitude modulation of the emulsion instead of phase modulation. However, this method is not desirable, since the diffraction efficiencies in that case are very low.

Fig, 6 is a three-dimensional plot of surface relief grating 42*d*. Grating 42*d* is formed with openings 92 within protrusions 94, forming the relief of surface 96. The positioning of these openings 92 and protrusions 94 causes the main beam to split into four sub-beams.

Surface relief grating 42*d* is made, e.g., of a silicate material such as fused Silica, or a highly flexible polymer material such as PMMA or the like, and is formed by cutting uniformly sized openings or slits into the surface relief grating by processes including photolithography, electron beam direct writing, or interferometric recording.

The desired relief for the surface 96 is calculated according to the field distribution in the plane of the grating. For a desired field distribution of an array of $M \times N$ waves, the function of the output field can be written as:

$$U(x,y) = \sum_{m=1}^{M} \sum_{n=1}^{N} A_{mn} \exp(i\phi_{mn}) \exp[2\pi i(\alpha_m x + \beta_n y)] \qquad (8)$$

wherein:

A_{mn} is the amplitude;

ϕ_{mn} is the phase;

(α_m, β_n) is the direction of the (m^{th}, n^{th}) wave in the two dimensional array, and

(x,y) are the angular coordinates.

The field $U(x,y)$ can be written in terms of magnitude $|U(x,y)|$ and phase $\psi(x,y)$:

$$U(x,y) = |U(x,y)| \exp[i\Psi(x,y)], \qquad (9)$$

and the intensity distribution in the grating plane can be expressed as

$$I(x,y) = |U(x,y)|^2. \qquad (10)$$

Usually, in order to achieve the highest efficiency, it is desired to fabricate the grating as a pure phase element. Hence, the intensity function is clipped *to* $I(x,y)=constant$.

Clipping the intensity variations changes the optimal function of the grating and introduces errors. However, it is possible to practically eliminate these errors by optimizing the values ϕ_{mn}, which can be used as free design parameters. Therefore, the function $\Psi(x,y)$ can be calculated and the desired surface relief grating can be fabricated accordingly, where the contour of the relief grating can now be calculated as:

$$z(x,y) = \frac{\lambda}{(\nu - 1)} \mathrm{mod}\left(\frac{\Psi(x,y)}{2\pi}, 1\right) \qquad (11)$$

wherein

$z(x,y)$ is the depth of the relief;

λ is the wavelength of the laser, and

$\nu$is the refractive index of the grating.

With this approach, fan-out diffractive optical elements, having high diffraction efficiencies and sufficient uniformity, can be achieved.

There are different methods of actually manufacturing the surface relief grating. One method is to use direct writing means, like laser light or electron-beam devices, to fabricate a continuous surface-relief element. In another method, the desired grating is realized as a multilevel element, using photo-lithography techniques. Obviously, any desired grating arrangement can be fabricated, either as a surface relief grating or as a Bragg grating. That is, the number of the diffracted beams and the angular deviation between them can be arranged in any predefined, desired arrangement.

An alternative way to materialize the grating, instead of as a fixed grating as described above, is to exploit electronically controlled dynamic gratings. Recently, it has been shown that a high resolution, spatial light modulator (SLM) can be used to form an holographic element. Presently, the most popular sources for that purpose are liquid-crystal (LC) devices, but other dynamic SLM devices can be used as well.

Highresolution, dynamic gratings having several hundred lines/mm are known. This kind of electro-optically controlled diffraction gratings gives, in principle, 100% diffraction efficiencies and no polarization direction dependence, and can be used as the desired dynamic grating in the present invention, instead of the grating assembly described above in conjunction with Fig. 7. The operator can determine and set, in real time, the exact pattern and the distances between the burns, according to the condition of the patient and the desired treatment.

Fig. 8 shows a diffraction grating arrangement 46, for use as the diffraction unit 38 of the system 2, modified slightly so that the operating beam and the auxiliary beam do not reach the diffraction unit 38 on a coincident travel path, but rather, travel to the diffraction unit 38 along parallel paths. Accordingly, the main laser 10 and

auxiliary laser 16 are positioned so as to produce beams 6, 18 that travel in substantially parallel or parallel paths.

Diffraction grating arrangement 46 is such that it facilitates a wavelength shift between the main laser beam 6 (solid lines) and the auxiliary, preferably an aiming beam 18 (broken lines). Arrangement 46 employs two grating elements 98, 100, one for each beam 6, 18, in combination with a focusing lens 102, to create identical paths for the operating beam 6 and aiming beam 18 upon their undergoing splitting in the diffraction unit 46.

The two beams 6, 18 are not combined together, but they are arranged as two co-linear plane waves. The gratings 98, 100 diffract each beam into its respective wave and into the identical diffraction pattern. Therefore, the two beams 6, 18 are focused by the focusing lens 102 onto the same points in the image plane (IP).

Alternatively, should the system 2 be employed as shown in Fig. 1, the diffraction assembly 46 could employ the two different gratings 98, 100 separated sequentially, instead of laterally. That is, the main beam and the aiming beam are combined together, but two different gratings are inserted into the optical path during the aiming stage and the operating stage respectively, to create the same optical pattern on the treated area.

Obviously, the configurations described in Figs. 7 and 8 can be combined together. That is, each one of the gratings G_i in Fig. 7 can be a double grating as described in Fig. 8, for the main beam and the sub-beam, respectively.

A modification of the system 2 illustrated in Fig. 1 is shown in Fig. 9. The modification consists of eliminating the second light source unit 14 and instead, utilizing the main channel laser unit 10 to also provide an aiming beam for the main operating beam 6. This is achieved by the intensity-reducing device 62 as governed by the controller 104, capable of substantially reducing the radiation passing therethrough, to obtain a laser beam of reduced intensity. This reduced intensity beam is then used to accurately aim the main operating beam 6 on the target plane.

The system 2, when used to perform diabetic retinopathy, is such that the surgeon can place multiple burns with one shot of the operating laser beam. This results in fewer overall shots, as more burns are placed by the system of the present invention. When a PRP (pan retinal photocoagulation) treatment is desired, the whole retina, except for the macular area, is treated. In the case of significant macular diabetic retinopathy, a GRID treatment is performed, in a manner similar to the PRP treatment.

The system of the present invention can also be used for photodisruption treatments. In one such treatment, very short pulses of focused laser energy are emitted from the system 2, to cause optical breakdown and create cavitation through the expansion of a plasma bubble.

The system of the present invention can also be used for corneal photoablation treatments. In one such treatment, pulsed lasers, such as Er:YAG, CO_2 or Alexendrite are used as the main laser 10, emitting ultraviolet or near infrared wavelengths to break down molecules of the cornea and allow for the controlled removal of material with minimal damage to the surrounding tissue. The system 2 of the present invention quickens this procedure as compared to the conventional procedure, reducing the chances of unwanted eye movements.

Similarly, as a result of its production of multiple beams, system 2 of the present invention can be used in photorefractive keratectomy (PRK) procedures. By shortening the time of the procedures, the chances of centration errors are reduced.

Other ophthalmic procedures in which system 2 of the invention may be used include glaucoma treatment procedures, such as trabecular meshwork procedures, trabecular ablation and laser sinusotomy. System 2 can also be used for cyclophotocoagulation and laser cataract surgery, such as posterior capsulotomy, where the main laser 10 is a Nd:YAG laser or a Er:YAG laser. In posterior capsulotomy, the system 2 can be controlled so as to create a curved line of three to four sub-beams in a circular manner. Additionally, system 2 may be used in vitreoretinal surgery and in

procedures such as photovitrectomy. Here, the system of the present invention 2 would be used in conjunction with an aspirator, for removing the lased off vitreous.

The system of the present invention can also be used for oculoplastic and other cosmetic dermatological surgeries, when the main laser 24 is IR, CO_2, Er:YAG, or Alexendrite. The system is also useful in trabecular meshwork and photodynamic/photochemical therapy, using the same principle of multiple beams. Similarly, other procedures where the system is useful include removals of hair, lesions, tattoos, and wrinkles; skin rejuvenation; collagen shrinkage; acne and traumatic scar treatment; xanthelasma; cellulite reduction, and the like.

The system can also be used for hair transplants, as the diffraction grating allows for an array of holes to be drilled simultaneously into the patient's scalp. This results in the shortening of the procedure when compared to conventional methods.

The system of the invention can also be used for laser dentistry. Particularly, the system may eliminate the need for drilling and other procedures involving anaesthetic.

It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing illustrated embodiments and that the present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

CLAIMS

1. An optical system, comprising:

a powerful first light source forming a main light beam;

an optical arrangment for focusing said main light beam onto a target plane, and

a diffraction grating assembly having a plurality of diffraction gratings movably coupled in said assembly, for selectively introducing at least one grating in a plane transversing said main light beam;

each of said gratings having a predetermined pattern of grating functions for spatial modulation of said main light beam so as to divide the beam into a multiplicity of sub-beams to be focused on said target plane.

2. The system as claimed in claim 1, wherein said powerful first light source is a monochromatic light source, forming a monochromatic light beam.

3. The system as claimed in claim 2, wherein said light beam and said sub-beams are capable of effecting surgical procedures.

4. The system as claimed in claim 1, wherein said plurality of diffraction gratings is movable in translation.

5. The system as claimed in claim 1, wherein said plurality of diffraction gratings is angularly movable.

6. The system as claimed in claim 1, wherein at least some of said diffraction gratings are reflection gratings.

7. The system as claimed in claim 1, wherein said diffraction gratings are phase volume gratings.

8. The system as claimed in claim 1, wherein said gratings are surface relief gratings.

9. The system as claimed in claim 1. wherein said diffraction grating is a dynamic grating.

10. The system as claimed in claim 9, wherein said dynamic gratings are electronically controlled liquid crystal devices.

11. The system as claimed in claim 1, further comprising a second light source optically arranged to direct light onto said target plane for aiming purposes.

12. The system as claimed in claim 11, wherein said second light source is arranged to direct light onto said target plane along the optical path of said main light beam, in order to form on the target plane the same optical pattern substantially similar to the pattern of the main beam.

13. The system as claimed in claim 11, wherein said second light source is a monochromatic light source.

14. The system as claimed in claim 11, wherein said second light source is obtained by an intensity-reducing device attenuating the beam of said light source.

15. The system as claimed in claim 1, further comprising a third light souce optically arranged to direct light onto said target plane for illumination purposes.

16. The system as claimed in claim 1, further comprising an optical assembly arranged to view said target plane area.

17. A method for treating a target plane with a light beam, said method comprising the steps of:

providing a powerful first light source forming a main light beam and an optical arrangement for focusing said light beam onto a target plane;

providing a diffraction grating assembly having a plurality of diffraction gratings, each of said gratings having predetermined patterns of refractive indices for effecting spatial modulation;

selecting at least one of said diffraction gratings, and

positioning said selected diffraction grating in a plane traversing said light beam, so as to cause said beam to split into a plurality of sub-beams to be focused on said target plane.

18. The method as claimed in claim 17, comprising the further steps of:

providing a second light source and optical arrangement; and

directing light from said second light source onto the target plane to assist the aiming of said main and sub-beams onto said target plane.

19. The method as claimed in claim 17, comprising the further steps of:

providing a third light source and optical arrangement; and

directing light from said third light source onto the target plane for illumination purposes.

20. A method for treating a tissue at a surgical site, said method comprising the steps of:

providing a first laser for generating a beam of an intensity sufficient to affect said tissue;

providing an optical arrangement including at least one diffraction grating;

dividing said beam into a multiplicity of sub-beams and passing said beam through said diffraction grating;

directing said sub-beams onto the tissue, and

activating said first laser to treat the tissue.

21. The method as claimed in claim 20, further comprising the steps of:

providing a second laser for generating a second beam in alignment with a portion of said first beam, to produce an aiming beam directed onto said surgical site.

Fig.1.

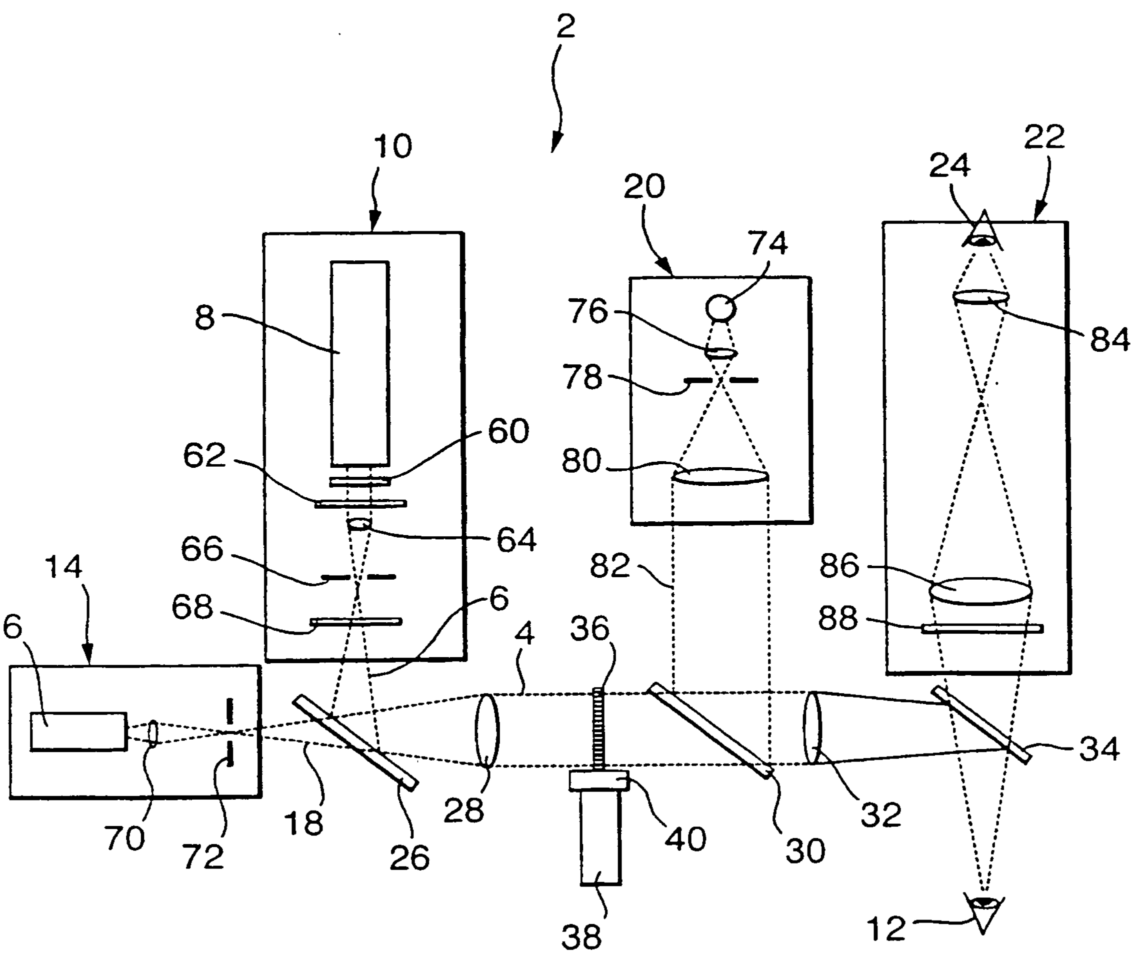
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Fig.2.

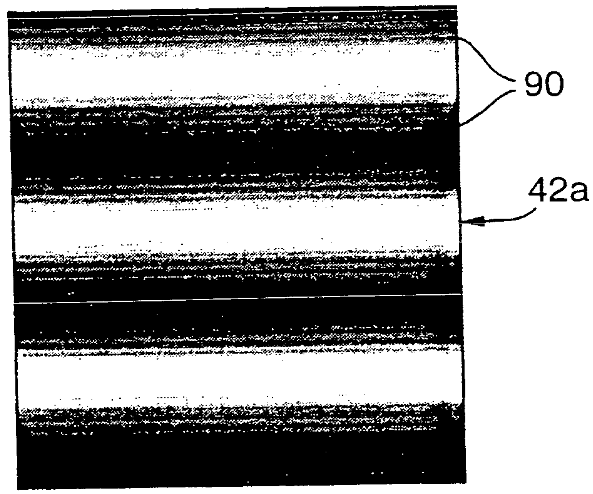

Fig.3.

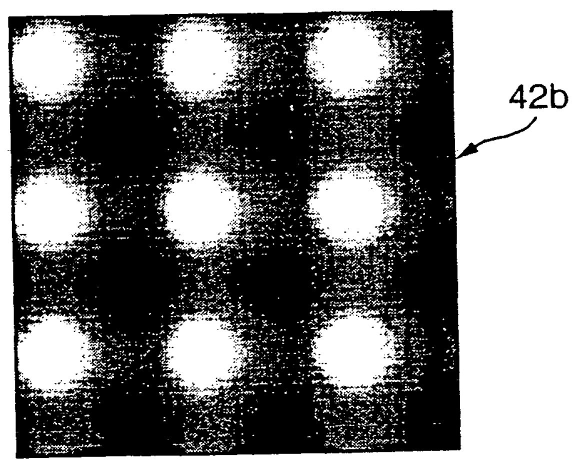

Fig.4.

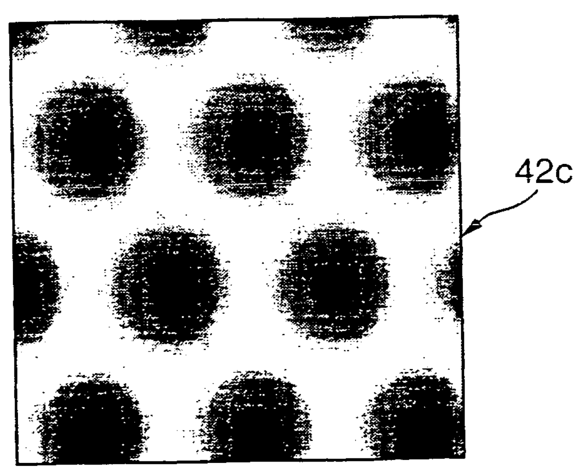

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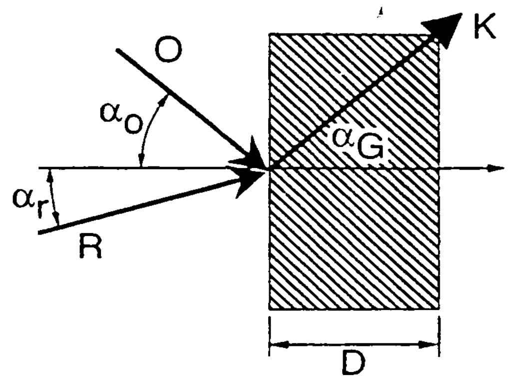
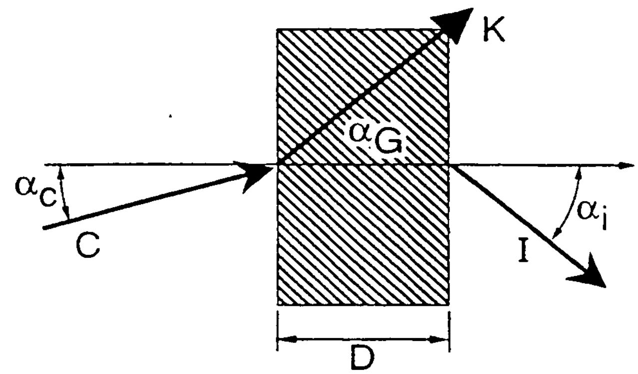
Fig.5a.



(a) Recording Geometry

Fig.5b.



(b) Readout Geometry

Fig.6.

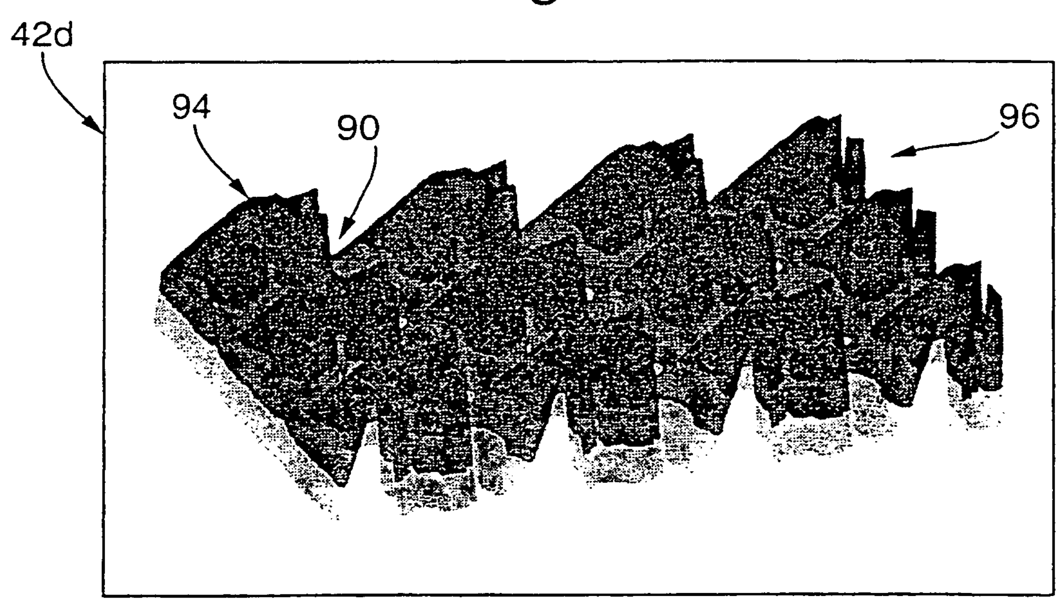
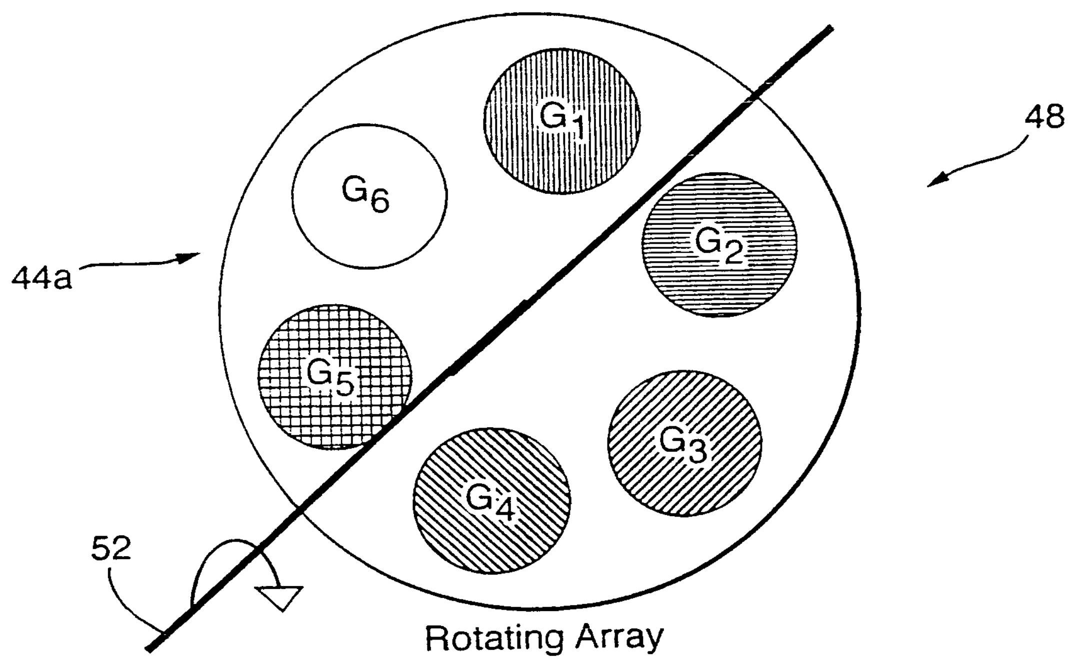


Fig.7a.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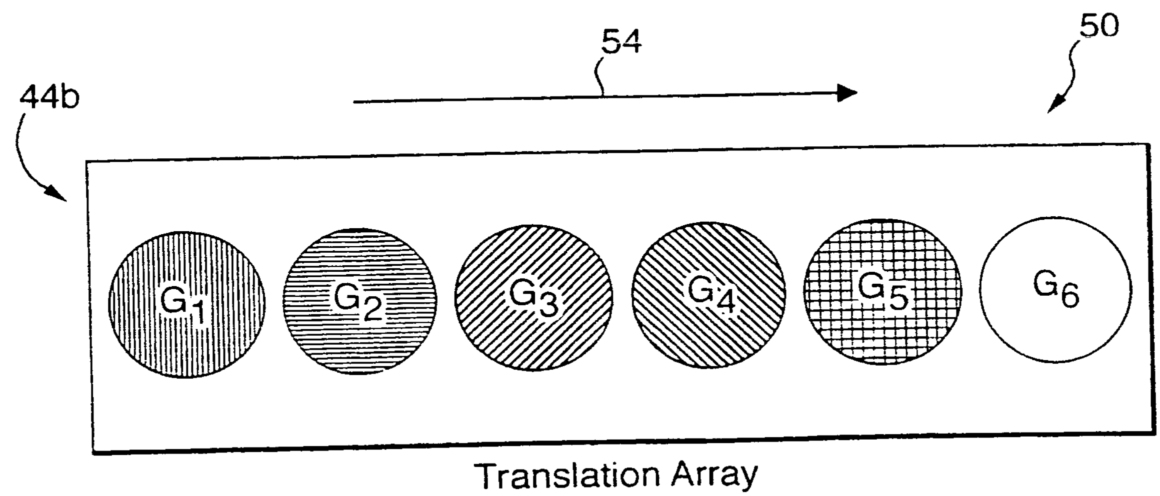
Rotating Array
G_1
G_2
G_3
G_4
G_5
G_6

Fig.7b.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44b
Translation Array
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G_3
G_4
G_5
G_6

Fig.8.

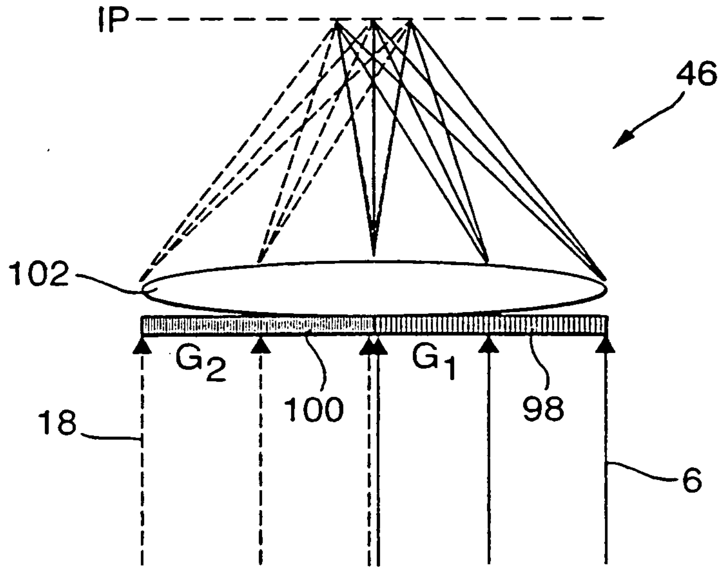
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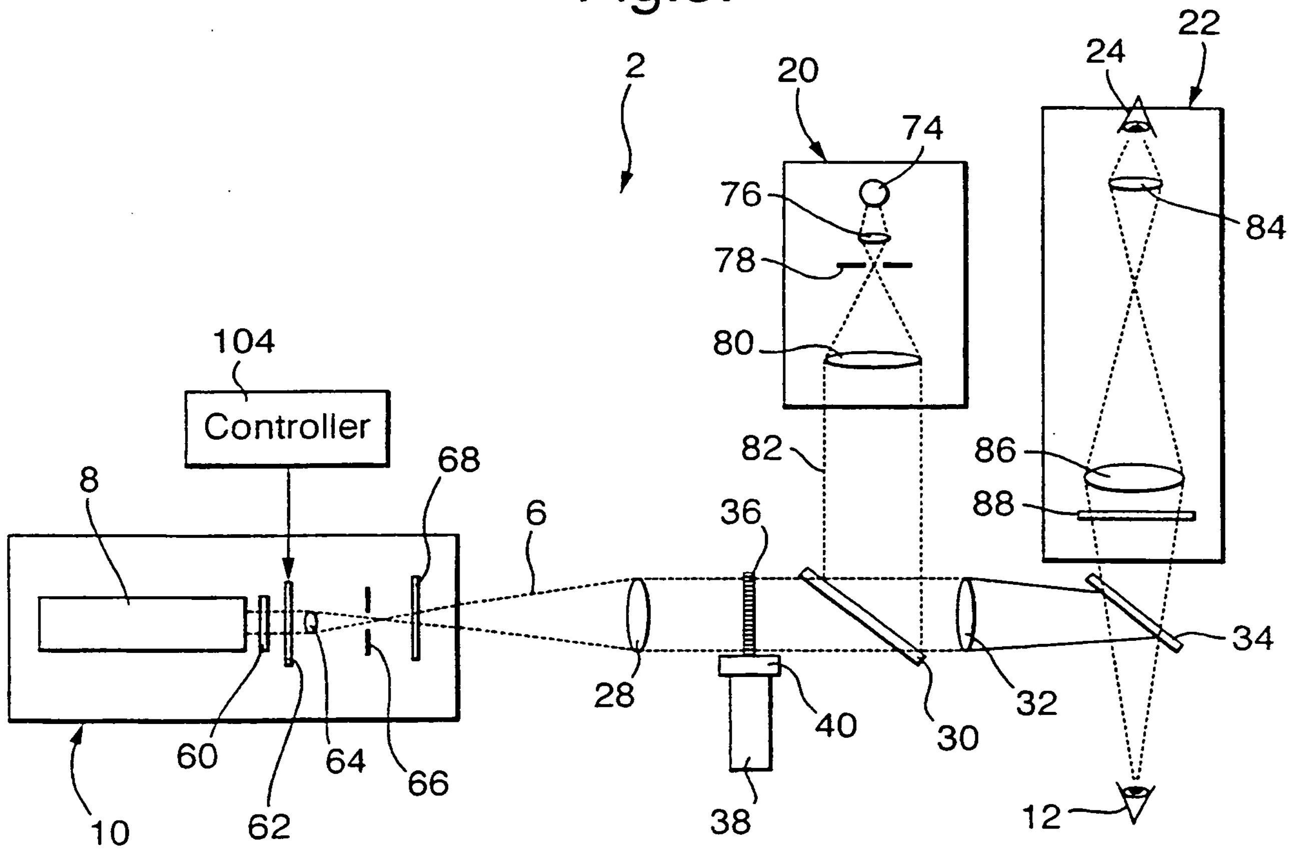
Fig.9.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INTERNATIONAL SEARCH REPORT

national Application No
PCT/IL 00/00762

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61F9/008 B23K26/067

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A61F B23K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 884 884 A (REIS) 5 December 1989 (1989-12-05) column 4, line 3 - line 22	1-16
A	US 5 921 981 A (BAHMANYAR) 13 July 1999 (1999-07-13) cited in the application the whole document	11,15,16
A	FR 2 715 480 A (GAILLARD) 28 July 1995 (1995-07-28) claims 2,6	6

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 February 2001	28/02/2001

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IL 00/00762

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